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Intelligent CNG Station Locator: A Dynamic Availability and Predictive Analytics System Utilizing Deep Learning, GIS in Mobile Application

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ABSTRACT: As Compressed Natural Gas (CNG) gains popularity in India as a cleaner and more economic friendly fuel alternative has led to an increased demand for efficient refueling infrastructure, drivers increasingly face the challenge of locating stations that have fuel available with minimal wait times. To address this, we've developed a smart mobile application that leverages a blend of deep learning, real-time data, and GIS (Geographic Information Systems) to simplify the refueling process. This app helps users quickly find nearby CNG stations and get reliable estimates on waiting times, making it easier to plan efficient refueling stops. What sets this system apart is its use of predictive models that learn from historical data and usage trends to forecast demand and congestion. This helps both drivers and station operators: users avoid unnecessary delays, while stations can better manage supply and resources. By combining location intelligence with AI-driven analytics, the system promotes a more streamlined, sustainable, and user-centric CNG refueling experience in growing urban areas.

KEYWORDS: Compressed Natural Gas (CNG), Mobile Application, Deep Learning, Geographic Information Systems (GIS), Predictive Algorithms, Fuel Availability Management.

I.INTRODUCTION

Compressed Natural Gas (CNG) stands out as an eco-friendly and cost-effective alternative to traditional fuels in the era of sustainable and economical fuel solutions. However, as its popularity grows, so does the difficulty of locating stations with available resources and minimal waiting times. Many drivers face challenges when searching for a nearby CNG refueling station, often encountering long queues and unpredictable availability that disrupt their schedules. Recognizing this issue, the Intelligent CNG Station Locator system has been developed to provide an efficient solution by combining the capabilities of deep learning and Geographic Information Systems (GIS) within a user-friendly mobile application.

This application leverages real-time data and historical trends to deliver accurate, dynamic information on CNG station availability, queue lengths, and predicted wait times, empowering drivers to make informed refueling decisions. By utilizing deep learning, the system can process vast amounts of data related to station usage patterns, traffic flow, and demand fluctuations, allowing it to predict peak times and periods of high congestion at various locations. GIS technology enhances this by mapping station locations, showing optimal routes, and allowing users to visualize nearby refueling options in real time. Together, these technologies enable the system to analyze and present complex data in an accessible way, providing a reliable and seamless experience for CNG users.

Beyond immediate availability, the Intelligent CNG Station Locator offers predictive analytics that assesses long-term patterns in CNG demand, helping station managers and suppliers optimize resource allocation. The application can identify high-demand areas and peak usage times, guiding the scheduling of refueling services and minimizing the likelihood of shortages. Furthermore, users receive personalized insights and alerts, such as notifications on low-traffic times or alternate routes to less congested stations, making the refueling process more efficient and reducing unnecessary delays.

By offering convenience, efficiency, and enhanced user experience, the Intelligent CNG Station Locator contributes to sustainable urban mobility and reduces the carbon footprint associated with prolonged idling at refueling stations. This innovative approach benefits individual drivers and supports broader transportation networks, enhancing the operational efficiency of CNG infrastructure while promoting green energy alternatives.

The 21st century is known to be the age of digital world. There has been the adoption of computers to a great extent. Today without computers and Internet one cannot survive as we are dependent on these machines for almost all our work. Taking into consideration starting from home to education till banking and even corporate functioning everything has now been automated to computers. Computers contain all our important data in the digital format. With this the need to store the digital data has increased and virtual environment has replaced the physical storage for storing all our credentials as shown in Fig. 1. The most devastating challenge of cloud is to prevent the unauthorized deletion of the stored data on cloud because one can easily delete the stuff without any proper authorization. The data deletion is totally dependent on deletion of nodes that are pointing to some information in Virtual Machine.

II. LITERATURE SURVEY

1. Real-Time Fuel Availability Systems:
Research on real-time information systems for fuel availability suggests that predictive and real-time data significantly reduce the wait times for drivers. Studies like those by Li et al. (2019) focus on using IoT sensors and data aggregation to relay current station statuses to drivers, highlighting the benefits of integrating live updates in reducing congestion at refueling stations. However, these systems often lack predictive analytics, which would help drivers plan refueling based on anticipated demand and queue lengths.

2. Predictive Analytics in Traffic and Demand Forecasting:
Predictive analytics has become essential in forecasting user demand across sectors, with applications in transportation management and fuel station analytics. Deep learning models, such as those reviewed by Zhang et al. (2021), have proven effective for demand prediction, as they leverage large data sets to identify patterns over time. These models are valuable in predicting peak hours and reducing wait times by advising drivers of off-peak refueling opportunities. The incorporation of historical and real-time data is particularly crucial in achieving accurate demand predictions, as shown in studies on queue optimization and demand forecasting for public transport hubs (Chen et al., 2020).

3. Geographic Information Systems (GIS) for Optimal Route and Resource Allocation:
GIS technology has long been used in urban planning and resource allocation, including fuel distribution. Research by Srinivas and Reddy (2018) demonstrates how GIS maps and spatial analysis can help users locate resources efficiently by mapping the shortest routes and integrating information on nearby facilities. In fuel management, GIS has been employed to visualize refueling station locations and optimize route planning, which is particularly useful for drivers seeking to minimize travel time to stations with shorter queues. Incorporating GIS with predictive analytics enables a dual function of visual guidance and demand prediction, providing a holistic approach to resource management.

4. Deep Learning for Queue Length Estimation and Wait Time Prediction:
Deep learning methods, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), have been extensively applied in traffic forecasting and queue length estimation (Wang et al., 2020). These models analyze real-time sensor data, historical station usage, and demand surges to provide users with accurate wait time estimates. By combining CNNs for spatial analysis with RNNs for temporal sequence prediction, deep learning models have successfully reduced queuing times in similar contexts, such as electric vehicle charging stations (Kim et al., 2021). This combination is highly applicable to the Intelligent CNG Station Locator, where dynamic availability and wait time predictions would aid in minimizing congestion.

5.Mobile Applications for Resource Management in Urban Mobility:
The use of mobile applications for managing urban resources has been studied in various contexts, such as parking availability and public transport tracking. Research by Zhao et al. (2022) emphasizes the role of user- friendly interfaces in the success of mobile solutions, especially those providing live updates on resource availability. User experience is crucial in such applications, with studies showing that intuitive design and real- time notifications significantly improve user adoption and satisfaction. For CNG stations, a mobile application with interactive maps and predictive analytics can empower users to make informed decisions, minimizing idle times and fuel consumption.

III. METHODOLOGY

This research project will be on CNG Station Locator Project integrates several key technological frame works, including Geographic Information Systems (GIS), machine learning algorithms, and real-time data processing,to deliver a comprehensive and user-centric solution. The system architecture is designed with a multi-layered approach to ensure that each component serves a distinct function while seamlessly interacting with others.

3.1Technology Used

3.1.1 Geographic Information Systems (GIS): GIS technology, in combination with Google Maps and Places APIs, forms the core of the location-based functionality, allowing for spatial data handling and geolocation.
3.1.2 Deep Learning (DL): Convolutional Neural Networks (CNNs) may be used to process live video feeds more accurately, enhancing vehicle recognition accuracy and reducing misclassification in queue monitoring.
3.1.3 Push Notification Services (e.g., Firebase Cloud Messaging): Sends real-time updates to users regarding CNG availability and queue status, helping users make informed decisions on which station to visit.
3.1.4 Mobile Application Development (Kotlin/Swift for Android/iOS): For user-facing applications that display maps, availability, queue predictions, and notifications in an intuitive interface.
3.1.5 RESTful API: Provides structured communication between frontend and backend, facilitating efficient data exchanges for station information, predictions, and real-time updates.
3.1.6 Data Analytics: Enables backend analysis of usage patterns, peak times, and demand forecasts. Analytics tools and algorithms assess data to optimize station resource allocation and improve service quality.
3.1.7 Database Systems (SQL/NoSQL): MySQL or MongoDB databases are used to store persistent data, such as station information, historical queue data, and analytics, while Firebase serves as a real-time database for instant updates.

3.2Software Used

3.2.1 OpenCV: Used for real-time video processing and car detection in queue management. It enables image manipulation, object detection, and recognition capabilities that help estimate queue length based on live video feeds.
3.2.2 Google Maps API: Provides mapping, geolocation, and routing services, allowing users to locate nearby CNG stations and receive directions.
3.2.3 Google Places API: Supplies data on CNG station locations, operational details, and amenities, which the app uses to give users station-specific information.
3.2.4 Firebase: Acts as a real-time database for handling dynamic data updates, such as CNG availability and queue length, ensuring that users receive current information.
3.2.5 Scikit-learn: A machine learning library that provides tools for model training, such as Linear Regression and Random Forest, for queue prediction and availability forecasting.
3.2.6
Flask / Django (Backend Framework): These frameworks provide RESTful API support, allowing the frontend to communicate with the backend server efficiently and handle complex request processing.

IV.IMPLEMENTATION

CNG Station Tracker is a station management application designed to empower users to make informed decisions about CNG refueling. The app leverages YOLOv8 object detection and machine learning to analyze station traffic, provides real-time wait time estimates, and includes an AI-powered station management system for operational efficiency. The primary objectives are:

1. Enhancing station efficiency by monitoring and analyzing vehicle traffic patterns.
2. Promoting better user experience through accurate wait time estimates and real-time updates.

4.1.1 System Development Methodology
1. User Registration & Account Creation
Users can sign up via email/phone, with secure storage of credentials (password hashing). Profile setup includes vehicle type, preferred stations, and notification preferences.

2. User/Admin Login & Authentication

JWT-based authentication for secure access. Admin portal to manage station data and system configurations.

3. Home Dashboard
Real-time station status with wait time estimates. Navigation features and station recommendations. Quick access to station analytics.

4.Core Features
Vehicle Detection (YOLOv8 + ML) Process video feeds from stations → YOLOv8 detects vehicles → ML model analyzes traffic patterns. Real-time results with wait time indicators (e.g., "High traffic – 15 min wait"). Wait Time Calculator: Generates wait time estimates based on vehicle types and current queue. Option to view historical patterns and peak hours. Station Management System: Monitors station operations. Analyzes traffic patterns and suggests operational improvements.

5.Database Stores
User profiles, station data, traffic patterns, and system configurations. Retrieves data for ML models and user history.
1.Station Tools Traffic Analyzer
Computes traffic patterns and suggests optimal refueling times. Queue Monitor: Tracks queue length and vehicle distribution in real-time.

V. WORKFLOW

4.1 Requirements Analysis and Planning
- Define Core Objectives: Identify the primary goals, such as locating CNG stations, providing real-time availability, estimating queue lengths, and delivering notifications.
- Gather Requirements: Collect user requirements through surveys or feedback, noting essential features such as CNG station filtering options (e.g., by distance, amenities) and real-time data accuracy needs.
- Feasibility Study: Evaluate the technical feasibility, data sources, and algorithms required to achieve real- time updates and accurate predictions.

4.2 Design System Architecture
- Architecture Layers:
- Frontend Layer: Design mobile and web interfaces to ensure an intuitive user experience for interacting with maps, station data, and notifications.
- API Gateway: Outline the API’s role in securely routing user requests to backend services.
- Backend Layer: Structure the backend to include business logic components such as station location, availability checking, queue prediction, and notification services.
- Data Storage Layer: Identify databases needed for CNG station information, real-time availability, historical queue data, and analytics.
- Data Flow and Interaction: Define the flow of data between frontend, backend, and data storage, ensuring secure and efficient exchanges through RESTful APIs.

4.3Develop Frontend InterfaceUI/UX Design
- Mobile Interface: Design responsive layouts using tools like Kotlin (for Android) and Swift (for iOS) to support map interactions, search functions, and notifications.
- Web Interface: Use React or Vue.js to create a web application version, ensuring consistency in functionality and user experience.
- Feature Integration:
  - Map View: Integrate Google Maps API to allow users to view nearby stations based on their GPS location.
  - Search and Filters: Implement filtering options for distance, operational hours, and amenities, enhancing user convenience in finding preferred stations.

4.4 Set Up API Gateway

- Request Handling: Develop a central request router that processes requests from users and admin interfaces, directing them to appropriate backend services.
- Authentication: Implement an authentication service using tokens (e.g., JWT) to secure user data and access control.
- Data Validation: Add input validation at the API level to ensure accurate and secure data transactions.

4.5 Implement Core Backend Services

- Station Locator Service:
  - Distance Calculation: Use the Haversine formula or Google Maps API to calculate distances between the user and stations.
  - Station Filtering: Develop algorithms to filter and sort stations based on user-selected criteria.
- Availability Checker:
  - Real-Time Data Retrieval: Integrate Firebase for real-time data management, allowing CNG stations to update their availability status instantly.

Data Accuracy Verification: Include checks to ensure data accuracy by verifying timestamps or using reliability scores.

- Queue Prediction Engine:
- Data Collection: Aggregate historical queue data from each station and store it in a dedicated database.
- Model Selection: Use Linear Regression for simpler prediction tasks and Random Forest for complex, multi-variable queue estimations based on historical data.
- Model Training and Evaluation: Train the models on past queue data, evaluate accuracy with metrics like Mean Absolute Error (MAE), and refine models as needed.
- Notification Service:
  - Event-Triggered Notifications: Configure notifications to trigger when certain conditions are met, such as changes in availability or queue status.
  - Delivery: Use Firebase Cloud Messaging (FCM) to deliver real-time alerts to users' devices, ensuring they receive timely updates.
  -

4.6 Integrate with External APIs

- Google Places API: Use to fetch and display detailed CNG station information, including operating hours, contact details, and amenities.
- Machine Learning Models for Queue Prediction:
  - If using cloud-based machine learning services (e.g., AWS SageMaker or Google AI Platform), configure models to update predictions dynamically.
  - 4.5Establish Data Storage Solutions
- User Database: Store user profiles, preferences, and authentication data securely.

CNG Station Database: Set up a relational or NoSQL database to store CNG station details like location, hours, and amenities.

  - Real-Time Availability Database: Use Firebase for real-time data updates, allowing station operators to update status and reflecting changes immediately.
  - Historical Queue Database: Store past data on queue lengths to support predictive analysis.
  - Analytics Database: Store data analytics insights for internal reporting and to aid in decision-making for station operators.

4.7 Implement Data Analytics and Reporting

- Data Analysis: Use collected data to identify peak usage times, user preferences, and demand patterns.
- Generate Reports: Provide station operators with insights on station usage, which can inform future resource allocation and optimize operations.
- Performance Metrics: Track and display performance metrics like average wait times, peak periods, and user satisfaction scores to support continuous improvement.

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4.8 Testing and Quality Assurance

- Unit Testing: Conduct unit tests on each backend module to verify the accuracy of core functions, like queue predictions and availability updates.
- Integration Testing: Test the end-to-end workflow between frontend, API gateway, backend services, and data storage.
- User Acceptance Testing (UAT): Involve real users in testing the interface, functionality, and responsiveness, collecting feedback for final adjustments.
- Performance Testing: Ensure that the system can handle high traffic, especially during peak hours, to maintain consistent response times.

4.9 Deployment and Maintenance

- Deployment: Deploy the application on a scalable cloud environment (e.g., AWS, Google Cloud) to handle growing traffic and ensure reliability.
- Monitoring and Logging: Implement monitoring tools to track system health, response times, and error rates, ensuring proactive issue management.
- Regular Updates and Model Retraining: Periodically update the application with new features and retrain machine learning models using recent data for improved prediction accuracy.
- User Feedback Loop: Continuously collect and incorporate user feedback to enhance app functionality and user satisfaction.

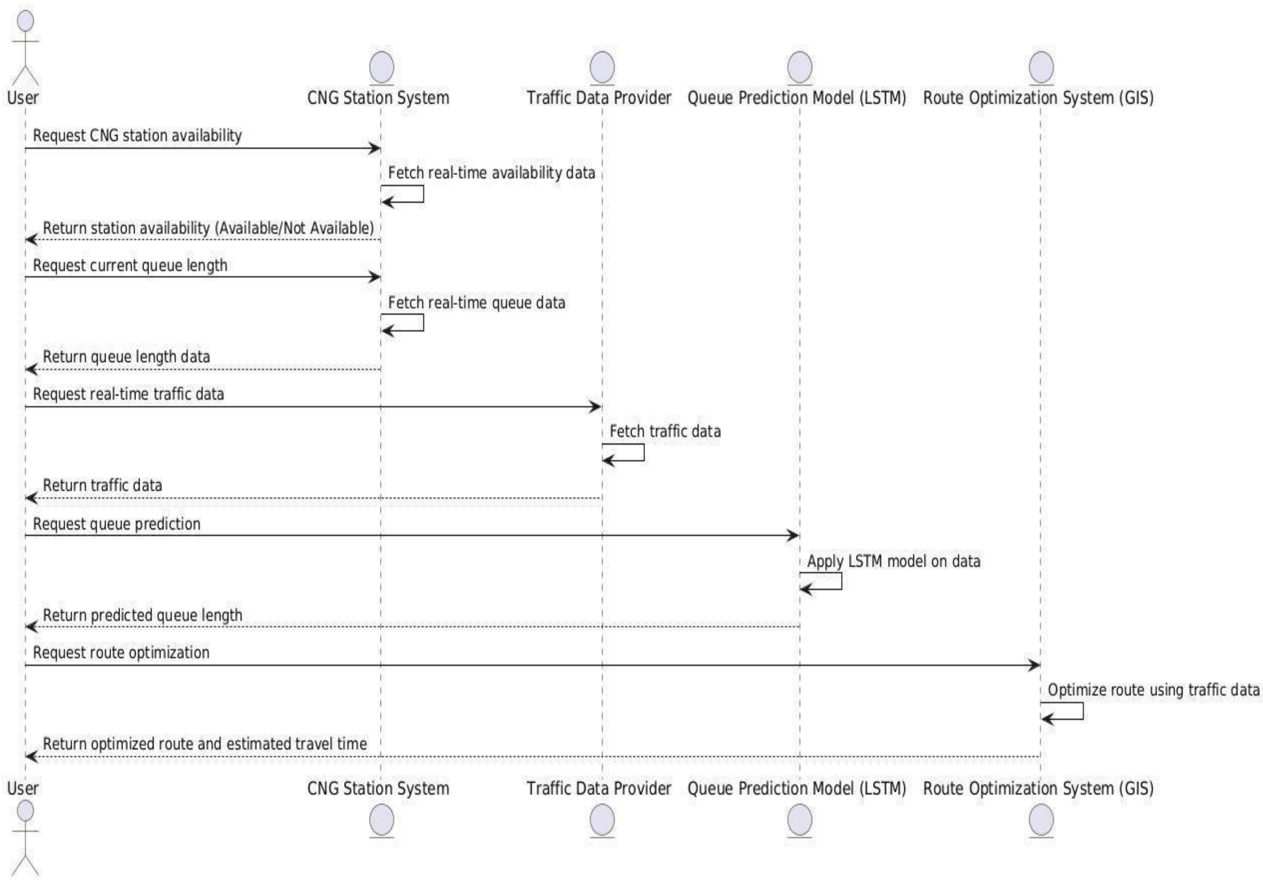

Figure 1: Sequence Diagram

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VI. TESTING

Testing is a methodology to determine if the actual software product aligns with the expected behavior and is free from errors. It involves the manual or automated execution of components within the app to assess one or more critical aspects. The primary objective of software testing in the realm of Android apps is to identify any defects, discrepancies, or deviations from the specified requirements

Module	Testing Approach
Vehicle Detection	1. Input: Process clear video feeds; verify YOLOv8 detects vehicles accurately. 2. Invalid Input Test: Poor quality video feeds; check error handling and recovery.
Wait Ti me Calcula tor	1. Queue-Based Calculation: Input vehicle counts and types; verify wait time estimates match processing durations. 2. Manual Override: Customize processing times; confirm wait time updates.
Station Management	1. Input station parameters in text format and verify operational suggestions. 2. Submit Unknown Conditions: Test unrecognized traffic patterns; check escalation to admin

Figure1: Testing Approach

Test Case ID	Test Case	Test Case I/P	Actual Result	Expected Result	Result (Pass/ Fail)
TC_REG_001	Test registration of a new User	Username: "test_user", Password: "test123", User Type: "User"	User registered successfully	User registration successful	Pass
TC_REG_002	Test registration of a new admin	Username: "admin_user", Password: "admin123", User Type: "admin"	User registered successfully	User registration successful	Pass
TC_AUTH_001	Test login with valid User credentials	Username: "test_user", Password: "test123", User Type: "User"	User logged in successfully	User login successful	Pass
TC_AUTH_002	Test login with valid admin credentials	Username: "admin_user", Password: "admin123", User Type: "admin"	User logged in successfully	User login successful	Pass
TC_AUTH_003	Test login with invalid credentials	Username: "invalid_user", Password: "invalid123", User Type: "User"	Authentication failed	Authentication failed	Pass

Figure2: Test Cases and Result

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Test Case ID	Test Case	Test Case I/P	Actual Result	Expected Result	Result Pass/Fail
TC001	Registration Process - Valid Input	User enters valid registration details	Registration successful	User account created	Pass
TC002	Registration Process - Invalid Input	User enters invalid registration details	Registration failed	Error message displayed	Pass
TC003	Authentication Process - Valid Credentials	User enters valid login credentials	Authentication successful	User logged in	Pass
TC004	Authentication Process - Invalid Credentials	User enters invalid login credentials	Authentication failed	Error message displayed	Pass
TC005	Verify accurate vehicle detection	User views clear video feed	Vehicles detected successfully	Vehicle count recorded	Pass
TC006	Handle poor quality video feed	System receives blurry video	Displays " Video quality poor" error with retry option	Error message displayed	Pass
TC007	Security Prevention	Malicious login attempt	Blocks request and logs inciden	Malicious activity recorded	Pass

Figure 3: Acceptance Test Cases for Various Modules

VII. FUTURE SCOPE

The CNG Station Tracker holds significant potential for advancement as a smart refueling and station management solution. Future developments could include enhancing the YOLOv8 model to detect a wider range of vehicle types, integrating weather and traffic data for better congestion and wait time predictions, and improving user accessibility through an iOS version and offline functionality. Operational efficiency can be boosted by syncing with station maintenance systems and enabling smart staff scheduling based on usage patterns. Additionally, integrating AR and AI technologies could enable real-time queue estimation and capacity visualization, while smartphone-based remote monitoring would support streamlined station oversight. These innovations would transform the tracker into a holistic, intelligent ecosystem that optimizes both user experience and operational performance.

VIII. CONCLUSION

A comprehensive and integrated system has been successfully developed, providing a unified solution to address the challenges associated with CNG station management. This platform empowers users with real time information on CNG availability, vehicle queue lengths, and estimated refueling times, significantly enhancing the refueling experience. Conventional systems fail to offer dynamic updates, leading to inefficient refueling and prolonged wait times. Our system overcomes these limitations by integrating GPS technology, predictive analytics, and machine learning to ensure optimal operations. The predictive models help forecast fuel demand, while queue management features reduce congestion and waiting periods. Additionally, the platform offers mobile-based convenience with route optimization and real-time notifications. In summary, this project successfully delivers a streamlined and user friendly solution to CNG users and providers alike, facilitating better planning and decision-making.

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